

COOLING PERFORMANCES OF THE COOLING SYSTEM USING FERROFLUID FOR HIGH POWER IGBT DEVICE

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ABSTRACT

Background/Objectives

The objective of this study is to numerically investigate the cooling performances of the cooling system using for high power IGBT device with the magnetic field intensities.

Methods/Statistical Analysis

The governing equations for the ferrofluid are continuity, momentum, energy, Magnetization and Maxwell's equation to analyze the heat transfer characteristics of the ferrofluid in the cavity. The governing equations are calculated by using both GSMAC (generalized simplified maker and cell method) suggested by Kawai and FEM (finite element method).

Findings

The thermal behaviors of the ferrofluids in the cavity were enhanced with the increase of the magnetic field intensity. The turbulence in the cavity observed apparantly due to the rapid promotion of the heat transfer phenomenon as the magnetic field intensity was increased. The average Nusselt numbers of the ferrofluids with the volume fractions of 4.5 % at $H = 5000$ A/m, $H = 10000$ A/m, $H = 15000$ A/m and $H = 20000$ A/m increased by 262%, 365%, 394% and 416% than those of $H=0$ A/m, respectively. The average Nusselt numbers of the ferrofluids with the volume fractions of 6.0 % at $H = 5000$ A/m increased by 31.0% and 8.0% than those of the volume fractions of 3.0 % and 4.5 %, respectively. In addition, in the case of 20000 A/m magnetic field intensity, the increasing rates showed 11.0% and 2.0% than those of the volume fractions of 3.0 % and 4.5 %, respectively. As a result, the average Nusselt numbers were constantly about 15 maintained after 20000~70000 A/m of the magnetic field intensity.

Improvements/Applications

The developed cooling system using ferrofluid could be applicable to the micro and miniature high power and heat flux electric and electronic devices required for compactness.

KEYWORDS: Average Nusselt Number, Cooling, Ferrofluid, IGBT & Magnetic Field Intensity

Original Article

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INTRODUCTION

As electronic devices are developing with higher performance, components of integrated circuits have become with smaller size and higher power. But these power modules are sensitive to temperature and it must operate below limited temperature¹. Therefore, it is an important to develop cooling devices with high efficiency and small size. The studies on the analysis of the cooling system for IGBT and the development of a high

efficiency cooling system have carried out in various application areas. Han *et al.*² developed the thermo-fluid simulation with the T-Q characteristic curve to evaluate the suitability of the cooling design with various operating conditions of the fan and IGBT module. Gillotet *al.*³ developed a high performance micro heat sink for the power multi-chip module and demonstrated the feasibility of the micro channel heat sink for the power multi-chip module. Recently, the cooling devices fused with the nano technology for IGBT with the high heat flux are researched⁴. In the example at the top, it is to apply the nanofluid with high thermal conductivity to the cooling device⁴. Ferrofluid among other nanofluids has the special characteristics. The ferrofluid as a novel cooling fluid was received much attention for the improvement possibility of cooling performance for electronic element with high heat flux such as IGBT (Insulated gate bipolar transistor)⁵. Foundational studies on the heat transfer characteristics of the ferrofluid in particular cavity have been published recently⁶⁻⁹. Lee and Seo¹⁰ conducted numerical research on natural convection characteristics such as flow velocity and an isotherm of the ferrofluid in a square cavity with various Rayleigh numbers. Lajvardiet al.¹¹ carried out an experimental study on the forced thermo magnetic convection and heat transfer performance of the ferrofluid. They reported that the heat transfer performance of the ferrofluid increases remarkably by applying the magnetic field. However, more pragmatic researches are required to promote applications of the ferrofluid in the related industry areas. This paper focuses on verification of heat transfer performances of the ferrofluid to apply to power electric elements with high heat flux such as IGBT. The objective of this study is to numerically investigate the effect of magnetic field intensity on cooling performances of the ferrofluid in a cavity with the various the magnetic field intensities. In addition, the average Nusselt numbers at the local heated surface of the cavity as heat transfer performance were analyzed with the various magnetic field intensities.

NUMERICAL METHOD

Figure 1 shows the numerical model of the cavity filled with the ferrofluid. Temperatures ' T_h ' on a local heated surface and ' T_c ' on the two local cooled surfaces of the cavity were maintained 373.15 K and 293.15 K, respectively, as shown in Figure 1 (b) . And the reference temperature in the cavity was maintained at 313.15 K. The magnetic field intensity was ranging from 0 to 100000 A/m with the interval of 10000 A/m and applied uniformly along x-direction at the left wall, and no-slip boundary condition was applied to all walls. The numerical model was filled with the ferrofluid in the cavity with thermo-physical properties as shown in Table 1. The volume fractions of magnetite were 3.0, 4.5 and 6.0%. The Rayleigh number was fixed at 10^5 as suggested by Hollands et al.¹². The thermo-physical properties of the ferrofluids used in this study were based on the data supplied by the manufacturing company¹³. Numerical analysis was performed during 20000 seconds per case.

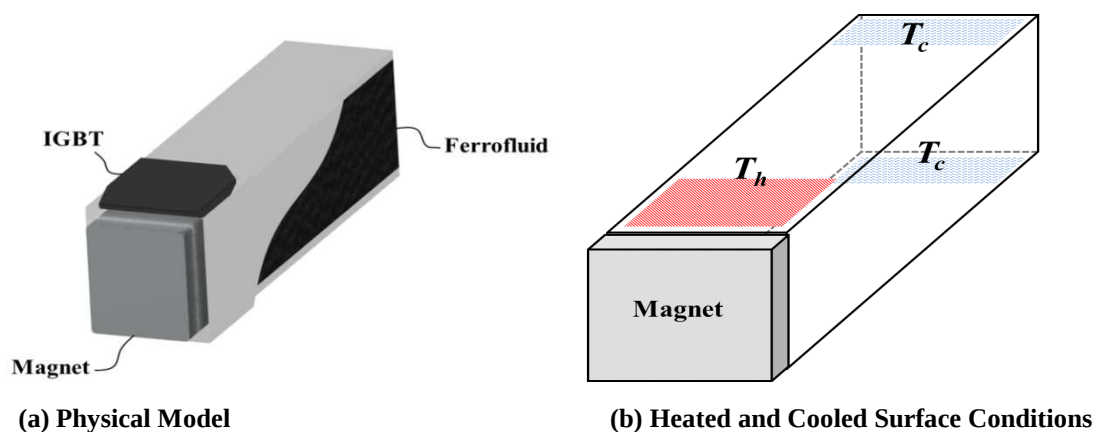


Figure 1: Analytical Model

Table 1: Thermo-Physical Properties of the Ferrofluid

Volume Fraction of Magnetite (%)	Nominal Particle Diameter (Nm)	Density (Kg/M ³)	Viscosity (Mpa·S)	Saturation Magnetization (Mt)	Prandtl Number
3	10	1142	3	18.3	23.1
4.5		1240	4	27.5	31.2
6		1305	4.7	33.6	36.6

The governing equations for the ferrofluid are continuity, momentum, energy, Magnetization and Maxwell's equation to analyze the heat transfer characteristics of the ferrofluid in the cavity¹⁴. There is expressed by equations from 1 to 6. The governing equations are calculated by using GSMAC (generalized simplified maker and cell method) suggested by Kawai¹⁵. This method is based on FEM (finite element method) and the fort ran power station 4.0 was used to calculate temperatures at ech nodes with times.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \quad (1)$$

$$\rho \frac{\partial \mathbf{u}}{\partial t} = \nabla \cdot \mathbf{T} + \rho \mathbf{b} \quad (2)$$

$$I \frac{d\Omega}{dt} = \nabla \cdot \Lambda + \boldsymbol{\varepsilon} : \mathbf{T} + \rho I \quad (3)$$

$$\rho T \frac{ds}{dt} = -\nabla \cdot \mathbf{q} + \Phi + \rho R \quad (4)$$

$$\mathbf{M} = \chi_m (\mathbf{I} - \tau \Omega \cdot \boldsymbol{\varepsilon}) \cdot \mathbf{H} \quad (5)$$

$$\nabla \cdot \mathbf{B} = 0, \nabla \times \mathbf{H} = 0, \mathbf{B} = \mu_0 \mathbf{H} + \mathbf{M} \quad (6)$$

$$\text{Nu}_{h.w} = \frac{T_{h.w} - T}{\Delta T} \frac{L}{\Delta y_{h.w}} \quad (7)$$

$$\overline{\text{Nu}} = \frac{\int_0^L \text{Nu}_{h.w} dx}{n+1} \quad (8)$$

The local Nusselt number on the near heated surface (T_h) was defined as an Eq. 7 based on the temperatures of the ferrofluid and distance with the heated surface. And the average Nusselt number was calculated using an equation 8 based on the exsting research results¹⁶.

RESULTS

Figure 2 shows the isotherms of the ferrofluids in the cavity with the increase of the magnetic field intensity with various volume fractions of the ferrofluid. As a result, the thermal behaviors of the ferrofluids in the cavity were enhanced with the increase of the magnetic field intensity. And the isotherms with various volume fractions of the ferrofluids were compared at 0 A/m, 5000 A/m and 10000 A/m of magnetic field intensity. In the case of 0 A/m magnetic field intensity,

this is not that much difference between isotherms of each volume fractions. However in case of 5000 A/m magnetic field intensity, there is a clear distinction between the heat transfer phenomenons of each volume fractions of magnetite in ferrofluid. The turbulence in the cavity is generated due to the rapid promotion of the heat transfer phenomenon as the magnetic field intensity was increased.

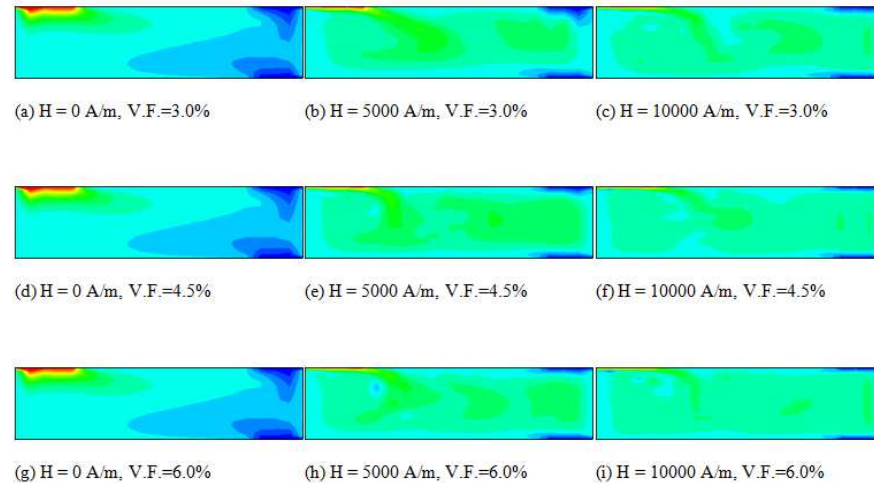


Figure 2: The Isotherms of the Ferrofluid in the Cavity with Various Magnetic Field Intensities

Figure 3 shows the average Nusselt numbers of ferrofluids at the local heated surface in the cavity with the increase of the magnetic field intensity. The average Nusselt numbers of the ferrofluids with the volume fractions of 4.5 % at $H = 5000$ A/m, $H = 10000$ A/m, $H = 15000$ A/m and $H = 20000$ A/m increased by 262%, 365%, 394% and 416% than those of $H = 0$ A/m, respectively. The average Nusselt numbers of the ferrofluids with the volume fractions of 6.0 % at $H = 5000$ A/m increased by 31% and 8% than those of the volume fractions of 3.0 % and 4.5 %, respectively. In the case of 20000 A/m magnetic field intensity, the increasing rates showed 11% and 2% than those of the volume fractions of 3.0 % and 4.5 %, respectively. The average Nusselt numbers are more reached to near 15, when the magnetic field intensity is increased. And there is a clear distinction between the average Nusselt numbers of the models of ferrofluid. In addition, the heat transfer performances are increased with the increase of the volume fraction of magnetite.

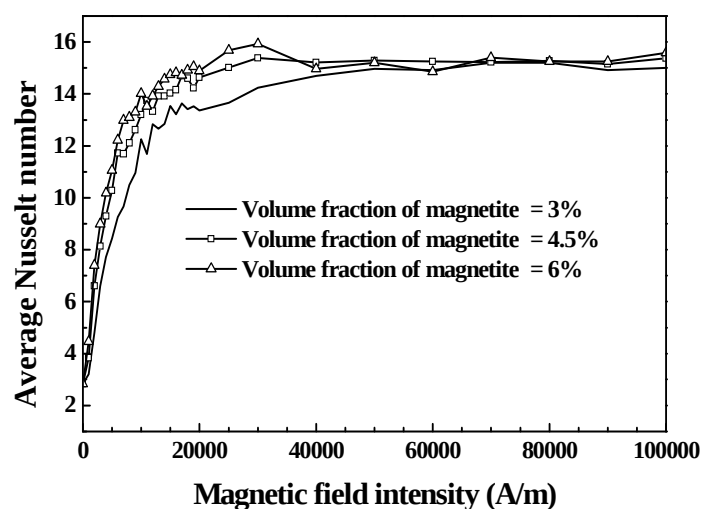


Figure 3: The Average Nusselt Numbers of the Ferrofluid with Heated Surface in the Cavity

CONCLUSIONS

This study investigated numerically the effect of the magnetic field intensity on heat transfer performances of the ferrofluids in the cavity with the various magnetic field intensities and the various volume fractions of magnetite.

- The average Nusselt numbers were increased rapidly with the increase of the magnetic field intensity until $H=20000$ A/m.
- The average Nusselt numbers of the ferrofluids with the volume fractions of 4.5 % at $H = 5000$ A/m, $H = 10000$ A/m, $H = 15000$ A/m and $H = 20000$ A/m increased by 262%, 365%, 394% and 416% than that of $H=0$ A/m, respectively.
- The average Nusselt numbers of the ferrofluids with the volume fractions of 4.5 % at $H = 5000$ A/m increased by 8.0% and 31% than those of the volume fractions of 3.0 % and 4.5 %.
- The average Nusselt numbers were increased with the rise of the magnetic field intensities and the rise of the volume fraction of magnetite due to the increased magnetic volume force of the ferrofluids.
- After 20000~70000 A/m of the magnetic field intensity, the average Nusselt numbers were constantly about 15 maintained.

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Nomenclature

T	Temperature
ρ	Density
B	Magnetic induction vector
H	Magnetic intensity
I	Idem factor
M	Magnetization vector
q	Heat flux vector
R	intensity of heat source per unit mass
Nu	Nusslet number
$V. F$	Volume fraction
Y	Position at y direction
Λ	Couple stress tensor

Ω	Rotational angular velocity vector of particle
ϵ	Levi-Civita symbol
Φ	Viscous dissipation function
χ_m	Volume magnetic susceptibility
τ	Relaxation time of a rotational motion by fluid friction
l	Volume couple vector per unit mass

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